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ABSTRACT

This study investigated the development of PCK (pedagogical content knowledge) within a group of 12 preservice chemistry teachers (all M.Sc.) during the first semester of their 1-year post-graduate teacher education program. The study focused on PCK with respect to a central issue in science teaching; i.e., relating macroscopic phenomena to microscopic particles. The collection of data involved two written questionnaires, interviews with every individual preservice teacher and their respective mentors, and an audio recording of a specific workshop session in the teacher education program. Results indicated a growing awareness among the preservice teachers concerning the need, in teaching situations, to explicitly relate the macro level and the micro level to each other. Moreover, the importance of the careful and consistent use of language was noticed by many preservice teachers. The growth of PCK appeared to be influenced mostly by the preservice teachers' teaching experiences. Also, the workshop appeared to contribute substantially. Finally, for some preservice teachers, their mentors appeared to have influenced the growth of PCK. Implications for science teacher education are discussed. (Contains 25 references.) (Author/YDS)

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The development of preservice chemistry teachersí pedagogical content knowledge

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Abstract

This study investigated the development of PCK within a group of twelve preservice chemistry teachers (all M.Sc.) during the first semester of their one-year post-graduate teacher education program. The study focused on PCK with respect to a central issue in science teaching, i.e., relating macroscopic phenomena to microscopic particles. The collection of data involved two written questionnaires, interviews with every individual preservice teacher and their respective mentors, and an audiorecording of a specific workshop session in the teacher education program. Results indicated a growing awareness among the preservice teachers concerning the need, in teaching situations, to explicitly relate the macro level and the micro level to each other. Moreover, the importance of the careful and consistent use of language was noticed by many preservice teachers. The growth of PCK appeared to be influenced mostly by the preservice teachersí teaching experiences. Also, the workshop appeared to contribute substantially. Finally, for some preservice teachers, their mentors appeared to have influenced the growth of PCK. Implications for science teacher education are discussed.

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Introduction

In recent years, researchers have shown a growing interest in the knowledge base of preservice science teachers. Shulman (1986) has introduced the concept of pedagogical content knowledge (PCK) to acknowledge the importance of the transformation of subject matter knowledge *per se* into "subject matter knowledge *for teaching*" (Shulman, 1986, p. 9). For preservice teachers, the subject matter knowledge they have acquired during disciplinary education constitutes one of the main bases from which their PCK may be derived. By getting acquainted with the specific conceptions and ways of reasoning of students, preservice teachers may start to restructure their subject matter knowledge into a form that enables the productive communication with their students (Lederman et al., 1994).

In this study, the development of PCK was explored within a group of preservice teachers of chemistry. In particular, our aim was to identify the influence of certain components of the preservice teacher education program (viz., specific workshops, student teaching experiences, and feedback from mentors) on this development. The purpose of this study was twofold. From a theoretical point of view, we aim to contribute to a better understanding of factors either promoting or hindering the development of PCK (cf. Grossman, 1990; Veal, 1998). Moreover, our study aims to contribute to the design of science teacher education courses.

Pedagogical content knowledge

Shulman (1987, p. 8) has described pedagogical content knowledge (PCK) as ë...that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understandingí. Research on PCK may contribute to resolving the ëblind spotí which results from a relative lack of research focusing on the content of the lessons taught (Shulman, 1986). In the last decade, numerous studies on PCK have been published (e.g., Van Driel, Verloop & De Vos, 1998). The key elements in Shulmanís conception of PCK are knowledge of representations of subject matter, and instructional strategies incorporating these representations on the one hand, and understanding of specific student conceptions and abilities on the other hand, both with respect to a specified content area. Obviously, these elements are intertwined and should be used in a flexible manner: the more representations and strategies teachers have at their disposal within a certain domain, and the better they understand their studentsí learning processes in the same domain, the more effectively they can teach in this domain.

Various scholars, elaborating on Shulmanís work, have proposed different conceptualizations of PCK, in terms of the features they include or integrate in PCK (e.g., Grossman 1990; Marks 1990; Cochran, DeRuiter, & King 1993; Veal 1998). Yet it seems that all scholars agree on Shulmanís two key elements, that is, knowledge of instructional strategies incorporating representations of subject matter, and understanding of specific student conceptions and abilities. In addition, there appears to be

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agreement on the nature of PCK. First, as PCK refers to *particular topics* it is to be discerned from knowledge of pedagogy, of educational purposes, and of learner characteristics in a general sense. Secondly, because PCK concerns the *teaching* of particular topics, it may turn out to differ considerably from subject matter knowledge per se. Finally, all scholars suggest that PCK is developed through an integrative process rooted in classroom practice, and that PCK guides the teachersí actions when dealing with subject matter in the classroom. The latter supports the view of Van Driel, Verloop and De Vos (1998) that PCK is a central component of teachersí practical knowledge or craft knowledge (cf. Grimmett & MacKinnon, 1992).

Grossman (1990) has identified four sources that are of importance with respect to the development of PCK: (a) observation of classes, both as a student and as a preservice teacher, often leading to tacit and, sometimes, conservative PCK; (b) disciplinary education, which may lead to personal preferences for specific educational purposes or topics; (c) specific courses during teacher education, of which the impact is normally unknown; and (d) classroom teaching experience.

Within the domain of science teaching, several studies have been performed on the development of PCK, in the context of both preservice and inservice teacher education. From these studies, the following factors influencing the development of PCK, emerge:

- *Knowledge of subject matter.* The development of PCK does not start until teachers have acquired a "deeply principled conceptual knowledge of the content" (Smith & Neale, 1989). Gess-Newsome and Lederman (1993) have noted that the subject matter structure of preservice science teachers is often vague and fragmented at the start of their teacher education program. During this program, the preservice teachers usually develop more coherent and integrated subject matter structures. However, the development of PCK may be hindered by the complexity of teaching practice.
- *Teaching experience with respect to specific topics.* According to Lederman et al. (1994), the development of PCK among preservice science teachers is promoted by the constant use of subject matter knowledge in teaching situations. Initially, preservice teachers appear to separate subject matter knowledge from general pedagogical knowledge. As a result of teaching experiences however, these types of knowledge are being integrated.
- *Knowledge of studentsí conceptions and learning difficulties.* Preservice teachers may benefit from studying studentsí preconceptions with respect to a specific topic, and comparing and discussing these conceptions in relation to their own conceptions (Geddis, 1993). Such activitites may stimulate preservice teachers to generate transformations of subject matter knowledge and topic specific teaching strategies. Van Driel et al. (1998) have described the development of inservice science teachersí PCK as a consequence of their analyses of studentsí conceptions and types of reasoning.
- *Participating in specific workshops.* Clermont et al. (1993) have studied the effects of a short, intensive workshop on specific teaching strategies (i.e., chemical demonstrations). They found that the PCK of preservice science teachers participating in this workshop, developed towards that of expert teachers. On the other hand, however, Adams and Krockover (1997), found that workshops can have a negative effect, because they can stimulate preservice teachers to copy conventional instructional strategies, stressing procedures rather than student understanding.

Comparing these factors with the sources for PCK development, described by Grossman, we may suggest that (a) observation of classes may promote the knowledge of studentsí conceptions, (b) disciplinary education, naturally, constitutes the basis for knowledge of subject matter, (c) specific courses in teacher education might affect PCK, that is, knowledge of studentsí conceptions as well as knowledge of specific representations or teaching activities, and (d) classroom teaching experience may stimulate the integration of subject matter knowledge and general pedagogical knowledge, thus contributing to the development of PCK. The present study, among others, aims to improve the understanding of the relations between sources and factors influencing the development of PCK.

Context and scope of the present study

The present study was situated in the context of the first semester of a one-year post-graduate teacher education program, qualifying for the teaching of chemistry in the highest stages of secondary education (cf., Grades 10-12). Before entering this program, participants have obtained a masterís degree in chemistry. With respect to the development of PCK, the program was designed according to the following ideas:

- At the start of the program, the preservice teachers hold subject matter knowledge in an academic sense, together with beliefs about teaching and learning in general, and maybe some notions about the teaching and learning of specific topics.
- The development of knowledge and beliefs during the program is seen as an individual process of knowledge construction. This process is guided by teaching experiences as a preservice teacher in a secondary school, supervised by a mentor, on the one hand, and by institutional meetings and workshops and individual study of the literature on the other hand.
- With respect to the teaching of *specific topics*, the preservice teachers are encouraged to reflect on their own learning process as a student, in relation to their observations during classroom lessons, and their study of the literature, documenting specific teaching and learning difficulties. This results in the explicitation of teaching concerns, which form the basis for the preparation of lesson plans focusing on the topic under consideration. After teaching these lessons, the preservice teachers are encouraged to share their reflections and formulate new teaching concerns (De Jong, 1997).

During the first semester of the teacher education program, the preservice teachers work in couples or trios at the same school. In the first weeks of the course, the preservice teachersí activities at school mainly consists of observing and discussing their mentorís lessons. Next, the preservice teachers begin to teach their own classes (about four to eight lessons per week). During this semester, the preservice teachers also take part in institutional meetings and workshops, for two afternoons per week on the average. The main aim of these meetings and workshops is to stimulate the reflection and discussion on teaching experiences in relation to the relevant literature (e.g., on science education, pedagogy, educational pyschology), resulting in the explicitation of teaching concerns and intentions.

The present study focuses on a central issue in science teaching, that is, relating macroscopic phenomena to microscopic particles (Lijnse et al., 1990). We shall refer to this theme as *Macro-micro*. The *Macro-micro* perspective concerns the relation between observable phenomena, like chemical reactions, and macroscopic properties (e.g., boiling points, solubilities) on the one hand, and their interpretation in terms of corpuscular characteristics on the other hand (cf., De Vos & Verdonk, 1996). Obviously, the role of representations (such as models) serves as an intermediate between these two levels. As learning to relate these levels to each other constitutes one of the most important objectives of chemistry eduction, preservice teachers need to develop PCK in this domain. We assumed that the preservice teachers in this study, being educated as chemists, had developed a habit of ëjumpingí between the macro and micro level in a flexible, fast and often implicit way (cf., Johnstone, 1993). For secondary school students, however, relating the macro and micro level is often problematic. The conceptual demands of shifting between these levels can be overwhelming (see e.g., Andersson, 1990). Specifically, students tend to mix up these levels, for instance by attributing macroscoping properties to atoms or molecules (cf. De Vos & Verdonk, 1987; Lee et al., 1993). As studentsí learning difficulties in this domain have been investigated in several studies, it was decided to discuss some findings from the research literature during one of the institutional workshops, after two months in the first semester, in relation to the teaching experiences of the preservice teachers at that moment. For this purpose, every preservice teacher was asked to study the article by Harrison and Treagust (1996) as a preparation for the workshop. After the workshop, the preservice teachers chose a topic from the chemistry curriculum in which the relation between macroscopic phenomena and corpuscular explanations was dominantly present (e.g., explaining the precipitation of inorganic salts in terms of ionic bonding). They planned and taught one to three lessons about this topic, and discussed these lessons with their mentor in the usual manner.

This paper focuses on a description of the nature of the development of PCK among the preservice chemistry teachers. In particular, the paper addresses the following research question: *Is a development in the preservice teachersí PCK observable, and, if yes, what is the influence of specific factors (i.e., teaching experience, institutional workshops and the mentor) on this development?*

Design

The subjects of the study were a group of twelve preservice teachers of chemistry. Shortly before entering this program, all participants had obtained a masterís degree in chemistry. Seven preservice teachers were female, five were male. Their ages varied from 22 to 28 years. All of them had barely any teaching experience, or no teaching experience at all. Five preservice teachers followed the institutional program at Utrecht University, whereas the others participated in the program of Leiden

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University.

A qualitative in-depth study was designed. In order to monitor the development of PCK, data were collected at specific moments during the first semester of the one-year post-graduate reacher eduction program:

- In October í97, all preservice teachers responded to a written questionnaire, aimed at exploring their content knowledge and pedagogical content knowledge with respect to the *Macro-micro* issue (see appendix 1).
- In November ë97, the workshop sessions devoted to *Macro-micro* were recorded on videotape and subsequently transcribed. Two parallel sessions took place: one for the group of 7 preservice teachers at Leiden University and the other for the group of 5 preservice teachers at Utrecht University.
- In December ë97 to January í98, every preservice teacher was interviewed individually about his or her practical experiences and reflections concerning *Macro-micro* (see appendix 2).
- In the same period, the mentors of these preservice teachers were interviewed to investigate their view on the preservice teachersí knowledge and development concerning *Macro-micro* (see appendix 3).
- Finally, in the same period, the preservice teachers responded to a second questionnaire. This was similar to the first questionnaire, but focused on pedagogical content knowledge only (see appendix 1).

All interviews were audiotaped and transcribed verbatim. In the analysis of the data, a stepwise procedure was followed, to connect the data from the different sources regarding each individual preservice teacher (data triangulation, cf. Janesick, 1994). First, the answers to the first and the second questionnaire were compared to identify changes in the preservice teachersí PCK, in particular in their knowledge of specific learning difficulties of students. Next, the interviews with the preservice teachers were analyzed, focusing on the factors contributing to the development of elements of PCK. In addition, the interviews with the mentors were analysed, mostly to validate the preservice teachersí descriptions of their developments. Finally, the transcripts of the workshop sessions were analyzed, mainly to check the references preservice teachers made to these sessions during the interviews. The aim of this analysis was to describe each teacherís individual development. Subsequently, the results of the individuals were compared to identify common patterns in these developments, and factors influencing these developments. In this step, investigator triangulation (Janesick, 1994) was applied by comparing and discussing the interpretations of the two authors of this paper.

Results

In this section, the results of the comparison of the two questionnaires will be described first. These results give an indication of the changes in the preservice teachersí knowledge of specific conceptions and learning diffulties of students. Next, the results of the analysis of the interview data will be presented. These results provide an understanding of the factors that have contributed to the changes in the preservice teachersí PCK, that is, not only their knowledge of specific conceptions and learning diffulties of student, but also their knowledge with respect to the use of specific teaching activities and strategies. In addition, some changes in the preservice teachersí content knowledge will be described.

Questionnaires

Comparing the answers of the preservice teachers on the first and the second questionnaire, it appeared that more specific learning difficulties were described in the latter. In particular, of the 9 items in the questionnaire (see appendix 1), on the average 2.5 items were left unanswered (28%) in the first questionnaire (question 2), whereas 1.3 items were left blank on the average in the second questionnaire (11%). In addition, learning difficulties and studentsí conceptions were described in more detail and more specifically in the second questionnaire. On the average, 4.1 out of 9 items (45%) in the second questionnaire were answered more explicitly with respect to specific learning problems, as compared to the answers in the first questionnaire. Interestingly, many answers in the second questionnaire were stated in terms of a question students might ask with respect to the topic under consideration (e.g., ëWhy does the water evaporate, although its boiling point is 100ºC?í, in the case of heating water to 60 ºC; item 1). These changes are indicative of an increase in the preservice teachersí knowledge of specific conceptions and learning diffulties of students.

Analyzing the content of the changes in the preservice teachersí answers in more detail, reveals that these changes can be grouped into three categories:

1. No explicit description of learning difficulties

Changes in terms of a more extensive description, which is not explicitly related to problems or conceptions students might have. For instance, one preservice teacher answered to item 5 (dissolving of salt in water) with a short reference to a solution containing ions in the first questionnaire, while the answer to this item in the second questionnaire was ëExtending particulate model with ions and non-molecular substancesí.
Sometimes, changes in this category appear to reflect a growth in the preservice teachersí content knowledge. In particular, this was noted several times with respect to item 9 (Mixing of monochloromethane and sodiumhydroxide in ethanol). For instance, a preservice teacher had only written a question mark as a response to item 9 in the first questionnaire, while the answer to the second questionnaire referred to the possibility of the reaction being of the S_N1- or S_N2-type and how to distinct between these possibilities, without any reference to students.

2. Description of learning difficulties in general terms

Changes which consist of adding an explicit reference to studentsí problems or conceptions, but in a rather general or unspecific way. Changes of this type occurred relatively often for most of the items throughout the questionnaire. For example, a preservice teacher added ëIt will be difficult for them to understand what happens at the molecular levelí to his response to item 3 (dissolving sugar). Other examples include ëcomparing it to the melting of iceí as a response in the second questionnaire to item 2 (melting of stearic acid), or adding ëstudents may confuse this process with a decomposition reactioní in response to item 5 (dissolving salt in water).

3. Description of specific learning difficulties

Finally, changes were observed which consisted of the addition of specific learning problems and conceptions of students. In general, these changes were explicitly inspired by the preservice teachers experiences during classroom teaching. Examples in this category may be further divided into changes indicating an increased understanding of learning difficulties [a] in a *macro-* context, for instance, ëIn my class, students find it difficult to see that oxygen has been consumed. They think itís a decomposition reaction.í (after the burning of magnesium; item 4), [b] in a *micro-* context, for instance, ëStudents have difficulties understanding that indivual molecules of water have different velocities at the same temperatureí (item 1; heating water to 60 ºC), and [c] with respect to *relating a macro and micro context to each other* . Typical of the latter category are answers (in the second questionnaire) like: ëStudents ask why you donít feel anything when you put your finger in a solution of salt, whereas this solution is supposed to consist of positively and a negatively charged particles (dissolving of salt into water; item 5), or: ëStudents hold conceptions like "the molecules become warmer"í (heating water to 60 ºC; item 1).

Because not every difference between the answers in the second and the first questionnaire could be categorized into one of the three categories described above, it was not meaningful to calculate the exact figures of changes in each category. However, it was clear that changes in the third category were observed most frequently, followed by changes in the second category. Changes in the first category constituted the smallest portion of the total amount of changes.

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Interviews

From the interview data, it appeared that all but two of the preservice teachers in this sample had expanded their knowledge concerning *Macro-micro*. Their increase of knowledge concerned both content knowledge and PCK. With respect to the former, the preservice teachers demonstrated an increased awareness of the nature of atoms and molecules as models. Moreover, most of them had come to realise that they usually related the macro level and the micro level to each other in an implicit manner. Five of the preservice teachers stated that, in this respect, their use of language had often been very thoughtless, and needed to be given more care.

From the interviews with the preservice teachers and their mentors, it appeared that the growth of PCK concerned both key elements of PCK, that is:

[1] Knowledge of specific conceptions and learning difficulties of students. In particular:

- Ten of the preservice teachers reported an increased awareness that, during teaching, the macro level and the micro level need to be related to each other in an explicit manner. Most of them had noticed that moving from one level to the other quickly and implicitly, can create confusion among students.
- In addition to this, three of these ten teachers had noticed that their preference to reason in corpuscular terms often hindered their studentsí understanding, especially when discussing chemical experiments. However, as trained chemists, these teachers had experienced difficulties in refraining from the use of such terms.

[2] Knowledge of instructional strategies incorporating representations of subject matter. Specifically:

- Six of the teachers reported the successful use of specific teaching strategies, such as the use of specific visualizations, or the use of multiple modes of representation (e.g., chemical symbols and material models).
- Five of the teachers concluded that, when communicating with students, it is necessary to use specific terms in a clear and consistent manner, especially when it comes to distinguishing "the things we see" on the one hand, and "our explanations in terms of atoms and molecules" on the other hand.

Below, the factors contributing to the growth of PCK are analyzed in more detail. These factors are discussed in an order of decreasing impact.

Classroom teaching experience

Classroom experiences refer both to the observation of lessons by the mentor, or a peer preservice teacher, and to lessons the preservice teachers taught themselves. Such experiences with respect to *Macro-micro* were considered by the preservice teachers to have had the strongest impact on their PCK in this domain. It appeared that these experiences had an impact on both elements of PCK, in particular on the preservice teachersí knowledge of studentsí learning difficulties. This knowledge was promoted by:

- The questions students posed during lessons directly at the preservice teachers. For instance, studentsí difficulties to interpret chemical formulas in terms of both macro and micro were mentioned by three preservice teachers. Two others described their increased awareness of terms and ways of reasoning that are obvious for themselves, but not for their students. One preservice teacher had taught a group of students who would ask for an explanation as soon as her explanation contained unclarities. This had alerted the preservice teacher to specific misunderstandings.
- Correction of studentsí answers on written tests. One preservice teacher explicitly described the specific learning difficulties she had recognized while correcting studentsí written answers.
- The responses of students to specific assignments. For instance, one preservice teacher asked his students to draw pictures of a water molecule. He was very surprised by some of the results, and discussed these with the students.
- The observation of studentsí behavior during lessons taught by the mentor or a peer. Three preservice teachers discussed this factor explicitly. One of them explained that observing the studentsí responses to another teacherís approach facilitated her understanding of studentsí learning difficulties much more than teaching her own lessons, because then she "did not have enough time and space in my mind" to observe the studentsí responses.

It must be noted, however, that three preservice teachers reported that they had not observed particular learning difficulties during classroom experiences.

In addition to this, some preservice teachers also described the ways in which classroom experiences had affected their knowledge of representations of subject matter and related teaching strategies. In particular, they mentioned:

- The careful use of technical terms and jargon with respect to corpuscular ideas. In particular, some preservice teachers described that they had experienced the necessity to make a clear distinction between terms in a macro context and a micro context, and to explicitly relate these contexts to each other. In particular, three preservice teachers had concluded that they should start by focussing on phenomena, before discussing explanations in corpuscular terms. This conclusion was mainly inspired by responses of students to the preservice teachersí way of teaching, displaying confusion or misunderstanding.
- The use of visualizations as an adequate tool to facilitate studentsí understanding was reported by three preservice teachers.
- The use of a simple model or theory, that is useful and comprehensible for the students, in stead of a more advanced model or theory, the preservice teachers would have used in a scientific context.
- The use of several representational modes (e.g., graphic, symbolic, physical models) to demonstrate the relation between the macro and micro context. One preservice teacher had experienced that different representations facilitated the understanding of different subgroups of students within a class. Another preservice teacher had succesfully encouraged his students to design their own models to explain a specific phenomenon.

University-based workshop

All preservice teachers mentioned the impact of the university-based workshop. Prior to the workshop, all had studied the article by Harrison and Treagust (1996). During the workshop, this article was discussed in relation to the preservice teachersí classroom experiences in the first two months of the semester. In a general sense, this workshop had contributed to the preservice teachersí understanding that students develop their own conceptions, and that a teacherís approach may sometimes unintentionally promote specific misconceptions among students.

In addition, most of the preservice teachers described that reading and discussing the article had contributed to their understanding of specific learning difficulties and misconceptions of students. Some of them related the content of the article explicitly to specific classroom experiences. That is, some preservice teachers described parallels between the literature and their own experiences. One of them could use the article to explain some of the problems she had experienced. When she first observed students having difficulties relating the macro and micro context to each other, she hypothesized that her way of explaining had been deficient. After reading and discussing the article, she could interpret her studentsí problems in terms of abilities to deal with abstractions. This insight served as an inspiration for her teaching approach.

With respect to their knowledge of teaching strategies, the impact of the workshop was modest. This impact was described in rather general terms, for instance, "the workshop served as an alert to possible learning problems", or "it made me realise to be careful with models". Three preservice teachers explicitly stated that, at this stage of their development, they could not yet apply the content of the article to their teaching practice. It must be noted, however, that the article of Harrison and Treagust (1996) focuses on the description of studentsí conceptions and abilities, and contains only a small section on recommendations for classroom instruction.

For some preservice teachers, the workshop had apparently affected their subject matter knowledge. That is, reading and discussing the article had contributed to their own understanding of the relation between the macro and micro context. In one of the workshops, a discussion had taken place about the ontological status of molecules and atoms ("does an atom really exist?"). Consequently, some preservice teachersí reported an increased awareness of the role of models and representations in relating the macro and micro context. For one of them, the workshop had been the most significant influence on his knowledge about the macro-micro relationship.

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He described the workshop as "annoying, but in a positive sense".

Meetings with mentor

These meetings included preparatory talks, during which the preservice teacherís lesson plans were discussed, and meetings, focusing on the evaluation of specific lessons, taught by the preservice teacher. Five preservice teachers explicitly described a positive impact of discussions with their mentors concerning *Macro-micro*. A couple of them, who were supervised by the same mentor, had had lengthy and extensive discussions with this mentor about the relationship between the macro and micro context. These discussions had stimulated their awareness of studentsí problems in this domain, and of the necessity to be explicit these contexts and their relationship. Moreover, the mentor had suggested specific teaching strategies (e.g., using multiple representational modes), which the preservice teachers had applied in their lessons. Two other preservice teachers stated that they had benefitted from the knowledge their mentor had of specific learning difficulties of students concerning *Macro-micro* .

In other cases, mentors had succesfully tried to promote the preservice teachersí awareness of their use of language. Several mentors had observed that the preservice teachers mixed terms from a macro and micro context, thus creating confusion among their students. One of them stated that although the preservice teachers were able to relate the micro context to the macro context for themselves, they were unable to explain this relationship in an adequate way for students. This mentor reported he had been succesful in making the preservice teachers more aware of terms and reasonings they used, that were not obvious for their students. Another mentor noticed that, after discussing the observed use of language with the preservice teacher, her use of language became more thoughtful and explicit. The mentor suggested that this improvement was partly due to the effect of the workshop, which had occurred in the same period. Another mentor noticed many inaccuracies and mistakes in the explanations presented by a preservice teacher. He spent much time discussing these flaws with the preservice teacher, initially aiming mainly at improving her subject matter knowledge. In the end, the mentor observed a progression both in the field of subject matter knowledge as well as PCK. He, too, suggested that this progression was also related to the university workshop. Yet another mentor had concluded that the preservice teachersí content knowledge was far from adequate. According to his opinion, this lack of knowledge hindered the preservice teachersí development of PCK. He suggested that through gaining teaching experience, the preservice teachers would eventually solve this problem.

Discussion and conclusions

Most of the preservice teachers in this sample displayed a distinct development of PCK about *Macro-micro*. More striking, however, were the large differences between the developments of individual preservice teachers. Apparently, these differences were related to differences in these teachersí personal backgrounds and prior education, as well as to differences between school settings and supervising mentors (cf., Kagan, 1992). From the data it could be concluded that, as far as the *Macro-micro* perspective was concerned, for some preservice teachers the emphasis in their development was on subject matter knowledge, whereas others mainly developed PCK. Two preservice teachers who did not show a distinct development with respect to *Macro-micro* , reported during the interviews that they had been occupied mainly with developing their images of self as a teacher, in relation to developing general pedagogical knowledge (e.g., in the area of classroom management). With respect to PCK about *Macro-micro* , differences were noted among the preservice teachers as to the extent of their development. Some reported rather general notions, for instance in terms of having observed studentsí limited abilities to deal with models, or having become more aware of their inaccurate way of talking about the macro and micro contexts. Others, however, described specific learning difficulties and conceptions of students in considerable detail, or gave a precise description of a teaching strategy they had developed on the basis of their experiences. These differences in the extent of preservice teachersí development was apparent in the data from the questionnaires and the interviews.

The content of the preservice teachersí development of PCK may be summarized as follows. To different extents, they have become more aware of their own habit to ejumpí between the macro and the micro context in a fast and implicit manner. Moreover, most of them have observed that their usual way of reasoning may cause problems for students, who, for instance, became confused by the mixing of terms from a macro context and a micro context. Thus, they concluded that they should be very strict in their use of language, explicitly making a distinction between the macro and the micro context, and the relation between these contexts.

As for the factors contributing to this development, it became apparent that classroom experiences had the strongest impact. In the first place, different activities and events during classroom teaching had affected the preservice teachersí knowledge of specific learning difficulties of students. In the second place, their knowledge of representations and teaching strategies had benefitted from experiences during classroom practice. This strong impact of teaching experiences is consistent with the findings of other scholars (cf., Grossman, 1990; Lederman et al., 1994). The university based workshop session also had a substantial influence on the development of the preservice teachersí PCK. It is suggested that this impact may be explained by (a) the timing of the session, about half way the semester, and (b) the format, which focused on the preservice teachersí interpretations of the research literature in relation to their beliefs and teaching experiences. Thus, most preservice teachers could relate the content of the article by Harrison and Treagust (1996) to the learning difficulties and ways of reasoning of their own students. In addition, the workshop session had a minor impact on the preservice teachersí knowledge of specific teaching strategies. At the same time, however, reading and discussing the article appeared to have triggered the development of subject matter knowledge of at least a part of the sample of preservice teachers. Finally, for about half of the sample their mentor had been a major influence on their development of PCK about *Macro-micro*. It appeared that the influence of the mentors varied largely, due to (a) differences in the frequencies and intensities of the meetings between mentors and preservice teachers, and (b) variations in the extent to which the mentors were interested or involved in the *Macro-micro* perspective. Possibly, the mentorsí own PCK in this domain may vary considerably.

Obviously, the exploratory nature of the present study, and the small number of respondents involved in the study, limit the possibility to generalize these conclusions. In future research, we will continue to study the development of PCK in other samples of preservice teachers.

Finally, several implications for teacher education emerged from this study. In the first place, it may be recommended to integrate specific activities in classroom practice. For instance, the preservice teachers could be asked to analyze their studentsí answers to written tests or specifically designed assignments in terms of studentsí learning difficulties and conceptions in the domain of *Macro-micro*. Eventually, the preservice teachers could be stimulated to carry out small scale action research activities, for instance exploring the effects of specific teaching activities on their studentsí knowledge concerning *Macro-micro* .

In the second place, the use of articles from the educational research literature during university based workshops is recommended, provided that the timing and the format of these sessions enables the preservice teachers to relate their own experiences and beliefs to these articles. In the domain of *Macro-micro* , a rich base exists of useful literature, for instance documenting specific misconceptions, the effects of certain teaching approaches, and so forth.

Finally, the role of the mentors should be given special attention. The observed variation in the mentorsí approach and involvement is considered problematic. On the one hand, the mentorsí knowledge of the university based elements of the teacher education program should be improved, while on the other hand, the mentorsí ideas and experiences should be used as input in this program. Moreover, the meetings of mentors and preservice teachers should be arranged in a way that stimulates the preservice teachersí understanding of their mentorsí practical knowledge (cf., Zanting et al., 1998).

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Appendices

Appendix 1: Questionnaire about ëphenomena and particles in chemistry educationí

Below nine processes are listed which are included in the chemistry syllabus for specific grades:

Item 1 Grade 9 Heating a beaker with 100 ml water to approximately 60°C

Item 2 Grade 9 Melting of stearic acid

Item 3 Grade 9 Dissolving of 5 grams of sugar in 100 ml of water at room temperature

Item 4 Grade 9 Burning of 8 grams of solid magnesium

Item 5 Grade 10 Dissolving of 5 grams of salt in 100 ml of water at room temperature

Item 6 Grade 10 Dissolving of 0,10 mole pure acetic acid in 100 ml of water

Item 7 Grade 11 Mixing 50 ml of aceton with 50 ml of water

Item 8 Grade 11 Electrolysis of a solution of copperbromide

Item 9 Grade 12 Dissolving of monochloromethane gas and sodiumhydroxide in ethanol.

First questionnaire

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Question 1: Describe each process in terms of both phenomena and particles.

Question 2: Note which specific learning difficulties or conceptions you expect for each process, for students of the respective grades.

Second questionnaire

Note for each process specific learning difficulties or conceptions for students of the respective grades. You may refer to your experiences or observations during classroom teaching.

Appendix 2: Questions during the interviews with the preservice teachers

1. How would you -as a chemist- describe the relation between macroscopic phenomena and microscopic particles? Use examples to clarify your answer.

2. Why is it important to pay attention to this relationship: [a] during chemistry lessons at secondary schools, and [b] in institutional workshops in the teacher education program?

3. In what manner have you taught this relationship during your lessons?

4. Which learning difficulties and conceptions of students did you observe during these lessons?

5. Which specific aspects of the macro-micro relationship did you find difficult to teach?

6. To what extent have your ideas about this relationship been influenced by: [a] reading and discussing the literature (i.e., the Harrison and Treagust (1996) article), [b] your experiences during classroom teaching, [c] discussions with your mentor, and [d] other factors?

Appendix 3: Questions during the interviews with the mentors of the preservice teachers

1. In what manner(s) did the preservice teachers teach the macro-micro relationship during their lessons?

2. To what extent were the preservice teachers capable of diagnosing learning difficulties and conceptions of students with respect to this relationship?

3. Which teaching difficulties of the preservice teachers did you observe in this respect?

4. To what extent did the preservice teachers develop their ideas about teaching this relationship? How was a development expressed in their ways of teaching and discussing their lessons?

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